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Signal Processing volumes 1 and 2, to appear in IMA Volumes in Mathematics and its Applications, Springer-Verlag, New York. (In progress, copies will be sent to the Air Force Office of Scientific Research when available.)

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—IMA

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February 28, 1989

Dr. Charles J. Holland, Director
Mathematical and Information Sciences
Department of the Air Force
Air Force Office of Scientific Research
Bolling Air Force Base, DC 20332-6448

RE: GRANT #: AFOSR-85-0134 and [redacted]

Dr. Holland:

I am enclosing our final reports for the grants entitled "Signal Processing" (AFOSR-88-0283) and "Stochastic Differential Equations, Scientific Computation and Applied Combinatorics" (AFOSR-85-0134).

accepted 3-15-89

Sincerely yours,

Willard Miller, Jr.

Willard Miller, Jr.,
Associate Director

enclosures: Final Reports
WM:kas

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PARTICIPATING INSTITUTIONS: Indiana University, Iowa State University, Michigan State University, Northern Illinois University, Northwestern University, Ohio State University, Purdue University, University of Chicago, University of Cincinnati, University of Houston, University of Illinois (Chicago), University of Illinois (Urbana), University of Iowa, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh Wayne State University
PARTICIPATING CORPORATIONS: Bellcore, Cray Research, Eastman Kodak, Honeywell, 3M

89

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

FINAL REPORT TO AFOSR

(1) CONTRACT OR GRANT NUMBER: AFOSR-88-0283

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(3) TITLE OF PROPOSAL: SIGNAL PROCESSING

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(6) LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER AFOSR SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

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[1] M. WERMAN, *A unified approach to the change of resolution: space and gray level*, SPIE Conference on Image Analysis (1988).

[2] M. WERMAN, *The capacity of k-gridgraphs as associative memory*, International Neural Network Society First Annual Meeting (1988).

[3] WITH D. MAGAGNOSC, *The relationship between integer and real solutions of constrained convex programming*, in progress.

[4] WITH M. SAKS, *Computing the majority function*, in progress.

[5] WITH D. KEENAN, *Producing curves with given singularities using symmetry sets*, in progress.

[6] WITH T. REED, H. WECHSLER, *Texture segmentation using Wigner filters and diffusion*, in progress.

[7] WITH PAUL LEMKE, *On the Complexity of Inverting the Autocorrelation function of a finite integer sequence, and the problem of locating n points on a line, given the* $\binom{n}{2}$ *unlabelled distances between them*, IMA Preprint Series, # 453 (1988).

(7) SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

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Signal Processing (see attached program for detailed information)

Signal Processing volumes 1 and 2, to appear in IMA Volumes in Mathematics and its Applications, Springer-Verlag, New York. (In progress, copies will be sent to the Air Force Office of Scientific Research when available.)

abstract

February 28, 1989

SIGNAL PROCESSING
JULY 2 - AUGUST 5, 1988
Volume #22 AND # 23

List of papers to appear (to date) in the Signal Processing Volumes.

AUTHOR	Title
Louis Auslander and Gertner	"Wide-band ambiguity function and $a \cdot x + b$ group"
Louis Auslander and Tolmieri	"On finite Gabor expansions of signals"
Joseph A. Ball & I. Gohberg and L. Rodman	"Sensitivity minimization and bitangential Nevanlinna-pick interpolation in contour integral form"
Gerard Bricogne and R. Tolmieri	"Two Dimensional FFT algorithms on data admitting 90°-Rotational Symmetry
C. Byrnes & A. Isidori	"Uniform bounded input-bounded output stabilization of nonlinear systems"
Ronald Coifman	"Wavelet analysis and signal processing"
E. Feig	"Estimating interesting portions of the ambiguity function"
Ciprian Foias (Tannenbaum)	"Operator theoretic methods in the control of distributed and nonlinear systems"
Bruce Francis	"Snippets of $\mathcal{H}_\infty$ Control Theory"
Gorin, Allen L.	"On the complexity of pattern recognition algorithms on a tree-structured parallel computer"
Alberto Grunbaum	"Soliton mathematics in signal processing"
Andrew Hasenfeld	"Selective 'complex' reflectionless potentials"
Herbert Hauptman	"The phase problem of X-Ray crystallography"
M. Hazewinkel	"Nongaussian linear filtering, identification of linear systems, and the symplectic group"
Christopher Heil	"Wavelets and frames"
Thomas S. Huang and A. Netravali	"Linear and polynomial methods in motion estimation"
Steven Izen	"Inversion of the X-ray transform from data in a limited angular range"
Charles R. Johnson	"Positive Definite Completions: Guide to Selected Literature"
Arthur Krener	"Nonlinear controller design via approximate normal forms"
E.B. Lee and W-S. Lu	Feedback with delays: Stabilization of Linear Time-Delay and Two Dimensional systems"
Hanoch Lev-Ari	"Extension problems under the displacement structure regime"
Alfred Louis	"The Eikonal approximation in ultrasound computer tomography"
Sanjeev R. Kulkarni, Sanjoy Mitter and T.J. Richardson	"An existence theorem and lattice approximation for a variational problem arising in computer vision"
Manfred Morari and Jay H. Lee	"Control structure selection: issues and a new methodology"
Harold Naparst	"Radar signal choice and processing for a dense target environment"
Frank Netterer	"Basic Algorithms in Tomography"
Todd Quinto	"Limited data tomography in non-destructive evaluation"
Larry Rabiner	"Speech recognition using pattern recognition methods"
Richard Roy	"ESPIRIT Estimation of signal parameters via rotational invariance techniques"
Kennem Smith, A. Faradani F. Natterer and E.L. Ritman	"Local and Global tomography"
D. Snyder & J. O'Sullivan	"High resolution radar imaging using spectrum estimation methods"
Gil Walter	"Recent extension of the sampling theorem"
Andrew Yagle	"Generalized split Levinson, Schur and lattice algorithms for estimation and inverse scattering"

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IMA NEWSLETTER #119

July 2 - July 15, 1988

1988 Summer Program
SIGNAL PROCESSING

NEWS AND NOTES

Summer Program on SIGNAL PROCESSING

June 27-August 5, 1988

Organizers: T. Kailath (Chairman), L. Auslander
A. Grunbaum, W. Helton, P. Khargonekar, S. Mitter

The program will be an integrated approach to one-dimensional and multidimensional problems in Signal Processing. The first two weeks will be devoted to a broad range of problems and methods. An effort will be made to promote new interaction also within one-dimensional research groups (such as the linear control and the nonlinear control people) and within the multi-dimensional groups (such as radar, sonar and medical imaging). The next four weeks will be somewhat less structured and will include periods of concentration in both 1-dimensional and multidimensional topics.

—

Participating Institutions Conferences

The Participating Institution Conferences for 1988-89 have recently been chosen, with a total IMA funding of $15,000. They are:

Several Complex Variables	Purdue University
Computer Aided Proofs in Analysis	University of Cincinnati
Algebraic Combinatorics	University of Michigan
Year of Concentration in PDE	Northwestern Univ. & Univ. of Illinois, Chicago
Orthogonal Polynomials & Applications	Ohio State University
Number Theory Conference	University of Illinois, Urbana

PARTICIPATING INSTITUTIONS:Indiana University, Iowa State University, Michigan State University, Northern Illinois University, Northwestern University, Ohio State University, Purdue University, University of Chicago, University of Cincinnati, University of Illinois (Chicago), University of Illinois (Urbana), University of Iowa, University of Michigan, University of Minnesota, University of Notre Dame, Wayne State University
PARTICIPATING CORPORATIONS:Bellcore, Cray Research, Eastman Kodak, Honeywell, 3M

SCHEDULE FOR JULY 2 - 15

Summer Program on
SIGNAL PROCESSING
June 27-August 5, 1988
Organizers: T. Kailath (Chairman), L. Auslander
A. Grunbaum, W. Helton, P. Khargonekar, S. Mitter

Weeks 1 and 2, June 27-July 10
Expository lectures on problem areas and methods

Unless otherwise noted, all talks are in **Vincent Hall 16**

Vincent Hall 16 is in the basement. Most of the offices of the participants and the mailboxes are located in the IMA facilities on the 5th floor of Vincent Hall.

Tuesday, July 5

9:00 am **Herbert Hauptman** — The Phase Problem of X-Ray Crystallography
Medical Foundation of Buffalo, Inc.

Abstract: The electron density function $\rho(r)$ in a crystal determines its diffraction pattern, that is, both the magnitudes and phases of its x-ray diffraction maxima, and conversely. If, however, as is always the case, only magnitudes are available from the diffraction experiment, then the density function $\rho(r)$ cannot be recovered. If one invokes prior structural knowledge, usually that the crystal is composed of discrete atoms of known atomic numbers, then the observed magnitudes are, in general, sufficient to determine the positions of the atoms, that is, the crystal structure.
The intensities of a sufficient number of X-ray diffraction maxima determine the structure of a crystal. The available intensities usually exceed the number of parameters needed to describe the structure. From these intensities a set of numbers $|E_H|$ can be derived, one corresponding to each intensity. However, the elucidation of the crystal structure also requires a knowledge of the complex numbers $E_H = |E|\exp(i\Phi_H)$, the normalized structure factors, of which only the magnitudes $|E_H|$ can be determined from experiment. Thus, a "phase" Φ_H , unobtainable from the diffraction experiment, must be assigned to each $|E_H|$, and the problem of determining the phases when only the magnitudes $|E_H|$ are known is called "the phase problem." Owing to the known atomicity of crystal structures and the redundancy of observed magnitudes $|E_H|$, the phase problem is solvable in principle.

10:00 am **Coffee Break**

10:30 am **Bruce Francis** — Snippets of H_∞ Control Theory
University of Toronto

Abstract: H_∞ control theory is now almost ten years old. The subject has several main parts: the mathematical theory of H_∞-optimization; extensions from the standard linear time-invariant framework to more general settings; methods for computing optimal controllers and associated software; results on design constraints and achievable performance, including tradeoffs between conflicting objectives; case studies of control system designs. In the past there have been several plenary talks on the big picture, a few expository papers, a critical analysis of the value of H_∞-optimization as a design methodology, a chapter in a research monograph, and a published set of course notes.

This talk is directed at non-experts and its goal is to pique their interest. Several fragments from the subject will be extracted for presentation.

2:30 pm **Frank Natterer** Basic Algorithms in Tomography
Westf. Wilhelms-Universitat Munster

Abstract: Four algorithms for the reconstruction problem in tomography are described: The Fourier algorithm, filtered backprojection, algebraic reconstruction techniques (ART) and direct algebraic methods. Their implementation, possible pitfalls, and relative merits are discussed. The intrinsic resolution of the reconstruction problem is compared with the resolution of the algorithms. A survey on further reconstruction algorithms is given.

4:00 pm **IMA Tea (and more!)** Vincent Hall 502 (The IMA Lounge)

Wednesday, July 6

9:00 am **Richard Askey** Some New Orthogonal Polynomials and What
University of Wisconsin, Madison Can Be Done With Them

Abstract: To be announced.

10:00 am **Coffee Break**

10:30 am **Larry Rabiner** Speech Recognition Based on Pattern
AT&T Bell Labs Recognition Techniques

Abstract: To be announced.

2:30 pm **Allen L. Gorin** On the Complexity of Parallel Algorithms for
AT&T Bell Laboratories Pattern Recognition on a Tree Machine

Abstract: I will describe results of recent investigations into the parallel computation of pattern recognition algorithms on a tree-structured parallel computer. I will furthermore describe the application of these ideas to the implementation of real-time speech recognition algorithms on the ASPEN tree machine.
One result has been to show the sufficiency of a tree interconnection and a host-orchestrated computing paradigm for efficient parallel execution of a broad class of pattern recognition algorithms. This is important since such an architecture has low interconnection overhead, leading to high-density compact implementations. For example, ASPEN has a burst throughput capability of over 2 GigaFLOPS in one cubic foot. This computing paradigm furthermore leads to scalable software, in which as the size of a problem increases, real-time execution can be maintained by merely scaling the hardware, with no change in either operating system or application code.
Methodology for decomposition and mapping of such algorithms onto the tree architecture will be presented and performance models that predict execution time as a function of problem and device-technology parameters will be derived. For a host-orchestrated computing paradigm on a tree machine, one can separately analyze computational and communications complexity of a parallel algorithm. Based on an analysis of the communications complexity of the algorithms, we will show their optimality plus the minimality of the interconnection topology. Finally, a benchmark analysis of a speaker-independent connected-word recognition algorithm on the ASPEN tree machine will be presented as proof of concept.

Thursday, July 7

9:00 am **Ronald Coifman** Wavelet Analysis, Signal Processing and
Yale University Operator Theory, I

Abstract: Various orthogonal and nonorthogonal expansions in terms of translates and dilates of a given function (wavelet), can be used as a substitute for Fourier analysis to obtain a time frequency decomposition

of signals. These have been used in sound and image processing as well as for diagnostic purposes. These kinds of expansions have been applied within pure mathematics in a variety of geometric settings (non homogeneous) to provide a flexible substitute for the Fourier Transform (Littlewood Paley theory). Linear and nonlinear operators exhibiting some scale invariance can be easily analysed in terms of wavelets providing both theoretical insight and fast numerical algorithms.

10:00 am **Coffee Break**

10:30 am **Jan C. Willems** — Modelling of Time Series
University of Groningen

Abstract: We will present an approach for exact and approximate modelling of multivariable time series. We start by discussing mathematical models, behavioral equations, and latent variables. Applying these ideas to linear time-invariant systems leads to a variety of system representations and parametrizations, among them the usual state space and input/output representations of these systems. Next, we will introduce the notion of the complexity of such systems. We finally turn to the modelling of time series. We view exact modelling as the computation of the most powerful unfalsified model. Approximate modelling, on the other hand, is regarded as a trade-off between complexity, misfit, and latency. In the end all this leads to concrete algorithms for approximate modelling of time series.

2:30 pm **Richard Tolimieri** — The Tensor Product in Algorithm Design
Center for Large Scale Computation

Abstract: The role of the tensor product in the design of finite Fourier transform algorithms will be examined. In a fundamental work, Temperton uses the language of the tensor product to give a unified account of the various forms of the Cooley-Tukey FFT algorithm, including variants due to Pease , Gentleman-Sande , Stockham and Korn-Lambiotte . The Agarwal-Cooley FFT can also be derived within Temperton's methods. The variants are distinguished by data flow which can be tailored to different computer architectures. See Swaratztrauber , for a discussion of implementation on vector computers. The manipulation of data flow by tensor product formulation can be extended to provide automatic code generation optimized for a specific computer.

The tensor product also plays a critical role in the multiplicative algorithms of Rader and Winograd. There are also variants using the tensor product. New algorithms based on these methods are derived offering several data flows with implementations on the micro VAX II. resulting in a more complete library of transform sizes and a 50% speed up as compared with the available DSP package.

SPECIAL LECTURE

3:45 pm **Katsuhisa Mimachi** — Representations of quantum groups and a q-analogue of orthogonal polynomials
Nagoya University

Abstract: The Peter-Weyl theorem for quantum group $SU_q(2)$ is shown in an explicit manner and a q-analogue of certain orthogonal polynomials is realized as the spherical functions for $SU_q(2)$. This gives the geometric meaning of such polynomials.

This work was done with T. Masuda, Y. Nakagami, M. Noumi and K. Ueno.

The talk will be held in Vincent Hall 570

Friday, July 8

9:00 am **Ronald Coifman** — Wavelet Analysis, Signal Processing and Operator Theory, II
Yale University

Abstract: Various orthogonal and nonorthogonal expansions in terms of translates and dilates of a given function (wavelet), can be used as a substitute for Fourier analysis to obtain a time frequency decomposition of signals. These have been used in sound and image processing as well as for diagnostic purposes. These

kinds of expansions have been applied within pure mathematics in a variety of geometric settings (non homogeneous) to provide a flexible substitute for the Fourier Transform (Littlewood Paley theory). Linear and nonlinear operators exhibiting some scale invariance can be easily analysed in terms of wavelets providing both theoretical insight and fast numerical algorithms.

10:00 am **Coffee Break**

10:30 am **Shmuel Winograd**, IBM — FIR Filters and Multiplication of Polynomials

Abstract: To be announced.

2:30 pm **Gerard Bricogne**, University of Paris/Sud — The Crystallographic Phase Problem from the Viewpoint of Statistical Detection Theory

Abstract: To be announced.

Weeks 3 and 4, July 11-24

Period of concentration: Digital filter & VLSI implementation. Integrable circuit modelling

During July 11-15 (week 3) the IMA has organized a special session on "Signal Processing" at the 1988 annual meeting of the Society for Industrial and Applied Mathematics (SIAM). The SIAM annual meeting is being held at the Hyatt Regency Hotel in downtown Minneapolis. The special session will consist of:

(1) One hour expository lectures by Gerard Bricogne (Mathematical Crystallography), Paris/Sud and CNRS, and Tom Kailath (Mathematics and Signal Processing), Stanford University.

(2) Two half day mini-symposia organized by:

(i) Donald E. McClure, Brown University
(ii) Mostafa Kaveh, University of Minnesota

We are also listing a minisymposium on association schemes organized by Dennis Stanton since it is an extension of the IMA 1987-88 program on Applied Combinatorics and the talks by Jim Glimm, Dan Joseph and Alan Newell since they are previews by organizers of the IMA 1988-89 program on Nonlinear Waves.

In addition, there will be a formal program of lectures in Vincent Hall in the afternoons of July 11 and 12, and an informal program for the remainder of the week. **During the Monday (July 11) afternoon program Tom Kailath will conduct a discussion of the informal part of the program for weeks 3 and 4. Those wishing to give informal talks are particularly encouraged to attend this session.**

Monday, July 11

SIAM Annual Meeting — Hyatt Regency Hotel, Minneapolis, Minnesota, Room Nicollet C-1

9:15 am **Gerard Bricogne**, University of Paris — The Mathematical Theory of the Crystallographic Phase Problem

Abstract: The X-ray analysis of crystal structure may be viewed as an inverse problem in which the three-dimensional structure of a crystal is to be reconstructed from the results of an X-ray diffraction experiment. The intensities of the scattered beams which can be measured in such an experiment are essentially the squared moduli of the Fourier coefficients associated to the triply-periodic electrom density distribution in the crystal. Unfortunately the corresponding phases cannot be measured, yet they must be restored by some means before the desired picture of the crystal structure can be obtained by Fourier synthesis. This constitutes the "Phase Problem" of X-ray crystallography. Because of the extreme practical importance of its solution, the Phase Problem has been under constant attack for over half a century, but there is

still no generally applicable method for solving it. Its recalcitrant nature derives from the fact that it is mathematically indeterminate unless sufficient chemical information is brought to bear on its solution to constrain it down to a reasonably unique answer, while the content of this chemical information cannot be adequately captured by any of the well-developed instruments of mathematics. The various techniques available at present to circumvent it all have their limitations, and are a constant source of difficulties. The speaker will review the mathematical aspects of existing phase determination procedures, including some of his recent work on a Bayesian statistical theory of the Phase Problem aimed at providing a new solution strategy. He will also examine the computational requirements of present and foreseeable developments in this field, and in particular the design of superfast Fourier transform algorithms optimally adapted to crystallographic symmetry groups.

SIAM Annual Meeting — Hyatt Regency Hotel, Minneapolis, Minnesota, Room Nicollet D-2

10:30 am **Donald E. McClure, organizer** (Brown University) — Minisymposium 1: Mathematical Aspects of Computational Image Analysis

Abstract: The goals of computer methods for analyzing digital pictures range from "low level" image processing (for example, image restoration) to "high level" problems in scene analysis and computer vision (for example, invariant recognition of objects). Increasingly, the methods and algorithms for performing these analyses are guided by mathematical concepts and models. Recently, connectionist models (neural networks) and Markov random fields have been prominent in this context. In return, the problems of image processing and computer vision are stimulating the development of new mathematics, for example, to better understand the behavior of algorithms for global optimization of objective functions on very high-dimensional domains. In this minisymposium, we will highlight selected interactions between mathematics and applications to image analysis.

Talks

Elie Bienenstock (Université Paris-Sud) — A Relational Approach in Object Recognition

Chii-Ruey Hwang (Academia Sinica, Taiwan) — Asymptotic Behavior of Simulated Annealing

S. K. Mitter & S. B. Gelfand (MIT & Purdue U.) — Recursive Stochastic Minimization Algorithms

The afternoon talks are in Vincent Hall 16

1:30 p.m. **André C.M. Ran** (Vrije University (Amsterdam)) — State space formulas for a model-matching problem

Abstract: We shall consider the following model-matching problem: given stable rational matrix valued functions T_1, T_2, and T_3 in realized form, we are looking for a stable controller Q such that $||T_1 - T_2 Q T_3|| < 1$. This problem has its origins in H^∞-control theory. Under the assumption that T_2 and T_3 are square matrix functions which have all their zeros in the open right half-plane a parametrization of all desired controllers Q will be given. This parametrization will be expressed in terms of the matrices appearing in the realizations of the functions T_i. A method to derive this parametrization has already been described in the book by B. Francis, but no explicit formulas have been derived there. Another method, using Nevanlinna-Pick interpolation, has been described among others by Kimura and by Limebeer. We shall follow the approach of Francis here.

2.30 pm **Coffee Break**

Immediately after the break, Tom Kailath will conduct a discussion of the informal part of the program for weeks 3 and 4. Those wishing to give informal talks are particularly encouraged to attend this session.

3:30 pm	**Hanoch Lev-Ari** Stanford University	Extension Problems under the Displacement Structure Regime

Abstract: This paper presents a unified approach to certain function-theoretic and matrix extension problems, which is based on the recently developed concept of matrices with a generalized displacement structure. We show that a variety of function extension problems, including Padé approximation and Caratheodory extension, are equivalent to the problem of extending a finite matrix with a given displacement structure into a larger (possibly infinite) matrix with the same structure. Moreover, such matrix extension problems can be efficiently solved by the same layer-peeling procedure that is used to determine the triangular factorization of matrices with a generalized displacement structure.
In general, the matrix extension problem mentioned above has many solutions. The set of all feasible extensions can be conveniently characterized in terms of the cascade model that is constructed by the layer peeling procedure: a particular extension is obtained by terminating the cascade model (which is the same for all extensions) with an arbitrary termination. Most often, the desired solution corresponds to a matrix extension that has finite rank. This is so, for instance when the Padé approximation is required to have minimal degree, or when the Schur-Caratheodory extension is required to have minimal H_∞ norm (but not so for maximum-entropy extension problems). We show that such finite-rank extensions correspond to choosing lossless terminations for the cascade model, and that the resulting extended matrix is intimately connected with the recently developed notion of generalized Bezoutians, which we describe in some detail.

—

Tuesday, July 12

3:30 pm	**IMA Tea** Vincent Hall 502	Reception, fruit, cheese, ice tea, lemon water

The afternoon talk is in Vincent Hall 16

4:00 pm	**Charles R. Johnson** College of William & Mary	Matrix Completion Problems

Abstract: To be announced.

—

Wednesday, July 13

SIAM Annual Meeting — Hyatt Regency Hotel, Minneapolis, Minnesota, Room Nicollet D-3

10:30 am	**Mostafa Kaveh, organizer** University of Minnesota	Minisymposium 15: Mathematics and Applications of Inverse Problems and Imaging

Abstract: Many imaging techniques, particularly those that involve tomographic reconstruction, solve the inverse problem of a multidimensional source-medium interaction model. Physical considerations for the generation of the measured data are used in the inversion process to determine (image) the unknown parameters of the postulated model. The speakers in this minisymposium will discuss the theory and applications of inversion in the context of a variety of tomographic imaging problems. Physical model validation, approximations for practical inversion and the accompanying computational issues will be addressed.

J. F. Greenleaf, and A. Chu Mayo Clinic	Comparison of Received Signals Predicted by Diffraction Tomography and Measured by Experiment
A.J. Devaney A.J. Devaney & Associates, Ridgefield, CT	Partially Coherent Emission Tomography

	S. Johnson University of Utah	Image Reconstruction by Inversion of the Exact Helmholtz Wave Equation
	B. Levy, and A. Ozbeck UC, Davis	Tomographic Methods for Geophysical Inversion
3:30 pm	**IMA Tea** Vincent Hall 502	Reception, fruit, cheese, ice tea, lemon water

The afternoon talk is in Vincent Hall 16

4:00 pm	**M.A. Kaashoek** Vrije University (Amsterdam)	A Review of Positive and Contractive Extension Problems and their Solutions

Abstract: Various positive definite and strictly contractive extension problems will be reviewed. The review will be based on an abstract approach that was developed by H. Dym and I. Gohberg, [DG, 1988] and has been extended by Gohberg, Kaashoek and Woerdeman [GKW, to appear]. This abstract approach provides a unified framework. It has been useful in solving and analyzing the Nehari problem and the so-called four block problem. One of the main points will be (see [GKW]) that the coefficients in the linear fractional map, which describes all solutions, can be read off from one special extension. Also it will be shown how the abstract results can be used to get state space formulas for rational solutions (cf. Gohberg, Kaashoek and Schagen, 1988).

Thursday, July 14

SIAM Annual Meeting — Hyatt Regency Hotel, Minneapolis, Minnesota, Room Nicollet C-1

9:15 am	**Alan Newell** University of Arizona	Solitons and Nonlinear Waves in Optics

Abstract: Nonlinear optics is a relatively new subject because nontrivial interaction between light and matter requires large intensities over relatively narrow bands of frequency. This talk will survey the Maxwell-Bloch equations, the equations of motion for light-matter dynamics, and introduce some of the exciting new developments connected with nonlinear wave propagation in fibers and waveguides, Snell's laws in nonlinear dielectrics, optical bistability in ring and Fabry-Perot cavities, Raman and Brillouin scattering, four-wave mixing, phase conjugation, multimode and soliton lasers. One or two models will be discussed in detail. A key message is that optics provides a rich source of stimulating problems for the applied mathematician, problems that are intellectually challenging, technologically promising and, above all, problems that display the full spectrum of interesting behavior of nonlinear partial differential and difference equations.

Friday, July 15

SIAM Annual Meeting — Hyatt Regency Hotel, Minneapolis, Minnesota, Room Nicollet C-1

8:30 am	**Daniel D. Joseph** University of Minnesota	Mathematical Problems Associated with the Elasticity of Fluids

Abstract: Flow and processing of viscoelastic liquids are the foundation of huge industries. But the mathematical properties that characterize the flow of these liquids are only beginning to be understood. The speaker will focus on the elastic properties of the viscoelastic liquids by expanding on an old idea of Poisson

and Maxwell that all liquids are ultimately elastic when the deformations are sufficiently rapid. Mathematically, the equations give rise to propagation of waves of vorticity and to steady "transonic" vorticity fields, just as in gas dynamics. In these vorticity fields, molecules adjust to new conditions by relaxing at different rates, the smaller molecules more quickly than the larger ones. The elephants never forget. The faster relaxations give rise to a viscous environment in which the slower, elastic, relaxations stay 'alive'. This produces a mix of wave behavior (hyperbolicity) and diffusion (parabolicity) not well understood mathematically because it does not fit into the standard classification. The speaker will show how their ideas manifest themselves in nature and will discuss the implications of mathematical structure for some problems that occur in numerical simulations of processing flows.

9:15 am **James G. Glimm**
Courant Institute

Adaptive Computational Methods

Abstract: Difficulties in numerical approximation and finding the physically important domains in the solution of a problem usually coalesce in the same subregion of solution space. Typically, the space-time coordinates are the independent variables while the solution state space is described by dependent variables. Adaptive computations balance the computational effort, in either space, by working harder where the answer is more difficult and/or the answer is more important. The independent variables are represented by a grid and adaptivity for them refers to adaptive grid construction. This can be accomplished by a choice of nonuniform grid spacings or by use of refined grids inserted into or overlapping with a primary uniform grid. Multigrid methods should be viewed as adaptive also, with the localization of computational effort occurring in wave number space or momentum variables conjugate under Fourier Transform to space variables. State space variables also allow localized consideration, as in the case with nonlinear waves, eigenmodes, rate-limiting chemical reactions and the equilibrium treatment which eliminates (undesirable) transients in rapid solution modes. The speaker will demonstrate representative grid and state space adaptive methods, together with illustrations showing the use of these methods in practical examples.

SIAM Annual Meeting
Hyatt Regency Hotel
Minneapolis, Minnesota
Room Nicollet D-1

10:30 am **Dennis Stanton, organizer**
University of Minnesota

Minisymposium 27: Association Schemes

Abstract: Several aspects of association schemes will be surveyed. One type of association scheme is a distance regular graph. Recent work on the classification of these graphs will be discussed. There are also classical orthogonal polynomials associated with the graphs, and combinatorial ramifications of their analytic properties will be given. Another type of association scheme occurs from a multiplicity free permutation representation of a finite group. These representations will be discussed, including the appropriate geometry on the coset spaces.

Paul Terwilliger
University of Wisconsin

The Classification of P and Q Polynomial Association Schemes

Eiichi Bannai
Ohio State University

Character Tables of Association Schemes

Dennis Stanton
University of Minnesota

Orthogonal Polynomials of Classical Association Schemes

Richard Weiss
Tufts University

S-Transitive and Distance Transitive Graphs

CURRENT IMA PARTICIPANTS

LONG-TERM VISITORS IN RESIDENCE

One Month or More

Averbuch, Amir	Tel Aviv University	Jun 26 - Aug 5
Brannan, James	Clemson University	Jun 26 - Jul 15
		Jul 31 - Aug 5
Butler, Lynne	Princeton U.	Jun 26 - Aug 31
Doerschuk, Peter	MIT	Jun 26 - Jul 22
Fassler, Albert	Ecole d'Ingenieurs Biene	Feb 1 - Jul 30
Friedman, Avner	IMA	
Gader, Paul	University of Wisconsin	Jun 27 - Jul 24
Games, Richard	MITRE Corp	Jun 27 - Aug 5
Garvan, Francis	U. of Wisconsin	Jun 26 - Jul 31
Habsieger, Laurent	U. Louis-Pasteur	Jun 26 - Jul 31
Hasenfeld, A.	Princeton U.	Jun 26 - Aug 6
Isakov, Victor	Courant Institute	Jun 17 - July 16
Itzikowitz, Samuel	Tel Aviv University	Jun 27 - Aug 5
Jerison, Meyer	Purdue University	Jun 26 - Jul 23
Johnson, Robert	Ctr. for Large Scale Comput.	Jun 27 - Jul 28
		Aug 1 - Aug 5
Kaveh, Mostafa	U. of Minnesota	Jun 27 - Aug 5
Khargonekar, Pramod	U. of Minnesota	Jun 27 - Aug 5
Lamken, Esther	IMA	Jun 26 - Sep 15
Lin, Shao-Shiung	National Taiwan University	Jun 15 - Aug 30
Luczak, Tomasz	Adam Mickiewicz U.	Jun 26 - Jul 31
Magagnosc, David	Dartmouth Coll.	Jun 26 - Aug 15
Miller, Willard	IMA	
Mitter, Sanjoy	MIT	Jun 26 - Jul 23
Mugler, Dale	Santa Clara University	Jun 26 - Aug 5
Naevdal, Geir	University of Trondheim	Jun 24 - Aug 7
Reed, Todd	University of Minnesota	Jun 15 - Aug 5
Rocha, Ana Paula	U. Do Porto, Portugal	Jun 26 - Aug 5
Rocha, Maria Paula Macedo	U. of Groningen, Netherlands	Jun 26 - Aug 5
Sell, George	University of Minnesota	
Simion, Rodica	George Washington University	Jan 13 - Jul 31
Trick, Michael	Georgia Inst. of Tech.	Jun 26 - Sep 13
Walter, Gilbert	U. of Wisconsin, Milwaukee	Jul 10 - Aug 5
Werman, Michael	Brown University	Jun 26 - Jul 31
Witten, Matthew	ETA Systems	Jun 19 - Jul 31
Yin, George	Wayne State U.	Jun 26 - Aug 6

SHORT TERM AND WORKSHOP VISITORS IN RESIDENCE

Allen, Jonathan	MIT	Jun 29 - Jul 10
Askey, Richard	U. of Wisconsin	Jul 4 - Jul 8
Auslander, Louis	CUNY	Jun 26 - Jul 1
		Jul 31 - Aug 5
Bernfeld, Marvin	Raytheon Co.	Jun 27 - Jul 10
Bistriz, Yuval	Tel Aviv University	Jul 8 - Jul 23
Boyd, Stephen	Stanford U.	Jul 11 - Jul 29
Brockett, Roger	Harvard U.	Jun 27 - Jul 8
Bruckstein, Alfred	Technion (Israel)	Jul 11 - Jul 22
Coifman, Ronald	Yale University	Jul 6 - Jul 8
Connor, Michael	City College of New York	Jun 27 - Jul 8
		Aug 1 - Aug 5

Davies, D. Huw	University of Edinburgh	Jun 26 - Jul 10
		Jul 31 - Aug 5
Francis, Bruce	U. of Toronto (Ontario)	Jul 3 - Jul 8
		Jul 25 - Jul 29
Fuhrmann, Paul	Ben-Gurion U. of Negev	Jul 9 - Jul 24
Georgiou, Tryphon	Iowa State U.	Jul 11 - Jul 23
Gertner, Izidor	Technion - Israel	Jul 3 - Jul 15
		Jul 31 - Aug 5
Gohberg, I.C.	Tel Aviv U.	Jun 27 - Jul 2
		Aug 1 - Aug 5
Gorin, Alan	AT&T Bell Labs	Jul 4 - Jul 8
		Aug 1 - Aug 5
Grunbaum, Alberto	U. of California-Berkeley	Jun 26 - Jul 1
		Aug 1 - Aug 6
Hauptman, Herbert	Medical Foundation of Buffalo	Jul 4 - Jul 6
Helton, William	U. of Calif.-San Diego	Jun 27 - Jul 2
		Jul 17 - Jul 30
Huang, Thomas	U. of Illinois-Urbana	Jun 27 - Jul 1
Johnson, Charles	College William & Mary	Jul 10 - Jul 29
Kaashoek, M.A.	Vrije U. (Amsterdam)	Jul 12 - Jul 27
Kailath, Tom	Stanford U.	Jun 26 - Jun 29
		Jul 10 - Jul 15
		Jul 18 - Jul 23
Lev-Ari, Hanoch	Stanford U.	Jul 11 - Jul 22
Levy, Bernard	U. of Calif.-Davis	Jul 11 - Aug 5
Mandrekar, V.S.	Michigan State U.	Jun 27 - Jul 10
Marr, Robert	Brokkhaven Nat'l Lab	Jun 27 - Jul 10
Mimachi, Katsuhisa	Nagoya University	Jul 3 - Jul 9
Natterer, Frank	Inst. f. Numer. U. Instrumentel	Jul 2 - Jul 9
Parzen, Emanuel	Texas A&M University	Jul 4 - Jul 15
Ran, Andre C.M.	Vrije U.(Amsterdam)	Jul 11 - Jul 29
Rao, Sailesh	AT&T Bell Labs.	Jul 11 - Jul 22
Roy, Richard	Stanford U.	Jun 27 - Jul 10
Sun, T. C.	Wayne State University	Jun 26 - Jul 8
Tolmieri, Richard	Ctr. for Lg. Scale Computer	Jun 27 - Jul 8
		Aug 1 - Aug 5
Tsao, Anna	AT& T Bell Labs	Jun 26 - Jul 10
		Jul 31 - Aug 5
Willems, Jan	U. of Groningen	Jul 3 - Jul 22
Winograd, Shmuel	IBM	Jul 4 - Jul 9
Woerdeman, Hugo	Free U. (Amsterdam)	Jul 11 - Jul 22
Yagle, Andrew	U. of Michigan	Jul 11 - Aug 5
Young, Nicholas	Glasgow U. (Scotland)	Jul 11 - Jul 29

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

University of Minnesota
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Minneapolis, Minnesota 55455
(612)624-6066 ima_staff%csfsa@umn-cs.cs.umn.edu

IMA NEWSLETTER #120

July 14 - July 31, 1988

1988 Summer Program
SIGNAL PROCESSING

NEWS AND NOTES

Summer Program on SIGNAL PROCESSING

June 27-August 5, 1988

Organizers: T. Kailath (Chairman), L. Auslander
A. Grunbaum, W. Helton, P. Khargonekar, S. Mitter

The program is an integrated approach to one-dimensional and multidimensional problems in Signal Processing. The first two weeks were devoted to a broad range of problems and methods. Efforts were made to promote new interaction also within one-dimensional research groups (such as the linear control and the nonlinear control people) and within the multi-dimensional groups (such as radar, sonar and medical imaging). The next four weeks will be somewhat less structured and will include periods of concentration in both 1-dimensional and multidimensional topics.

3M IMA JOINT SYMPOSIUM IN SIGNAL PROCESSING

On Tuesday, July 19 a Joint 3M-IMA Signal Processing Seminar will be held at 3M Center in Saint Paul. This will be an all day seminar, including tours of 3M laboratories, which will promote interaction between 3M researchers with an interest in the broad areas of signal processing, whether software or hardware applications oriented, or interested in theoretical aspects, and approximately 40 IMA mathematicians, physicists and engineers visiting from major universities and research groups around the world. The IMA participants will be bused to Saint Paul for the occasion.

Speakers representing 3M, and giving 30 minute talks, will be Bill Weaver (Software and Electronics Resource Center), Fred Waltz (Engineering System & Technology Laboratory), Sig Soli (Life Sciences Bio Research Laboratories) and A.B. Mahmoodi (Digital Imaging Applications Center). Speakers representing the IMA, and giving 60 minute talks, will be S. Rao (AT&T Bell Labs) and A. Bruckstein (Technion, Israel Institute of Technology). **The meeting is open but anyone who wishes to attend should register at the IMA office by July 11, 1988.**

PARTICIPATING INSTITUTIONS:Indiana University, Iowa State University, Michigan State University, Northern Illinois University, Northwestern University, Ohio State University, Purdue University, University of Chicago, University of Cincinnati, University of Illinois (Chicago), University of Illinois (Urbana), University of Iowa, University of Michigan, University of Minnesota, University of Notre Dame, Wayne State University
PARTICIPATING CORPORATIONS:Bellcore, Cray Research, Eastman Kodak, Honeywell, 3M

SCHEDULE FOR JULY 14 - JULY 31

Weeks 3 and 4, July 11-24

Period of concentration: Digital filter & VLSI implementation. Integrable circuit modelling

During July 11-15 (**week 3**) the IMA has organized a special session on "Signal Processing" at the 1988 annual meeting of the Society for Industrial and Applied Mathematics (SIAM). The SIAM annual meeting is being held at the Hyatt Regency Hotel in downtown Minneapolis. The special session will consist of:

(1) One hour expository lectures by Gerard Bricogne (Mathematical Crystallography), Paris/Sud and CNRS, and Tom Kailath (Mathematics and Signal Processing), Stanford University.

(2) Two half day mini-symposia organized by:

(i) Donald E. McClure, Brown University
(ii) Mostafa Kaveh, University of Minnesota

We are also listing a minisymposium on association schemes organized by Dennis Stanton since it is an extension of the IMA 1987-88 program on Applied Combinatorics and the talks by Jim Glimm, Dan Joseph and Alan Newell since they are previews by organizers of the IMA

Thursday, July 14 (Revised Schedule)

SIAM Annual Meeting — Hyatt Regency Hotel, Minneapolis, Minnesota, Room Nicollet C-1

9:15 am **Alan Newell**
University of Arizona
Solitons and Nonlinear Waves in Optics

Abstract: Nonlinear optics is a relatively new subject because nontrivial interaction between light and matter requires large intensities over relatively narrow bands of frequency. This talk will survey the Maxwell-Bloch equations, the equations of motion for light-matter dynamics, and introduce some of the exciting new developments connected with nonlinear wave propagation in fibers and waveguides, Snell's laws in nonlinear dielectrics, optical bistability in ring and Fabry-Perot cavities, Raman and Brillouin scattering, four-wave mixing, phase conjugation, multimode and soliton lasers. One or two models will be discussed in detail. A key message is that optics provides a rich source of stimulating problems for the applied mathematician, problems that are intellectually challenging, technologically promising and, above all, problems that display the full spectrum of interesting behavior of nonlinear partial differential and difference equations.

SIAM Annual Meeting — Hyatt Regency Hotel, Minneapolis, Minnesota, Room Nicollet C-1

2:00 pm **Thomas Kailath**
Stanford University
Mathematics and Signal Processing

Abstract: Signal processing is an eclectic discipline, combining ideas and tools from, among others, signal analysis, system theory, statistics and numerical linear algebra, many branches of mathematics and computer science, and analog and digital technology to design and implement algorithms for a wide variety of applications. Though the tools range from the very old to the very new, most of the development of signal processing has taken place in this century, especially in the last few decades. Zobel and Campbell introduced selective wave filters for telephony in the early 1900's. Heaviside and Carson provided the analytical tools for linear system analysis in the next two decades, while Brune and Cauer laid the mathematical foundation for network synthesis in the 1930's. Norbert Wiener contributed to several of these early developments, but also introduced a powerful new direction with his work in the early 40's on the statistical theories of prediction and filtering. In the early 50's, Shannon's information theory held out hope for dramatic gains

in downward compression and in reliable communication in noisy channels. In the 60's, the appearance of digital computers brought about a major revolution, releasing us from many prior limitations. Since then, there has been almost exponential growth in the field, many of the fruits of which are for example, almost common place today–the recovery of incredibly weak signals from outer space, high-speed communications over large computer networks and medical images of remarkable quality. Although no one can cover this vast panorama in any reasonable number of presentations, in his presentation, the speaker will show how even simple problems of linear prediction can involve a rich and mutually fruitful blending of ideas from many fields, especially various kinds of mathematics.

Friday, July 15

SIAM Annual Meeting — Hyatt Regency Hotel, Minneapolis, Minnesota, Room Nicollet C-1

8:30 am **Daniel D. Joseph**
University of Minnesota

Mathematical Problems Associated with the Elasticity of Fluids

Abstract: Flow and processing of viscoelastic liquids are the foundation of huge industries. But the mathematical properties that characterize the flow of these liquids are only beginning to be understood. The speaker will focus on the elastic properties of the viscoelastic liquids by expanding on an old idea of Poisson and Maxwell that all liquids are ultimately elastic when the deformations are sufficiently rapid. Mathematically, the equations give rise to propagation of waves of vorticity and to steady "transonic" vorticity fields, just as in gas dynamics. In these vorticity fields, molecules adjust to new conditions by relaxing at different rates, the smaller molecules more quickly than the larger ones. The elephants never forget. The faster relaxations give rise to a viscous environment in which the slower, elastic, relaxations stay 'alive'. This produces a mix of wave behavior (hyperbolicity) and diffusion (parabolicity) not well understood mathematically because it does not fit into the standard classification. The speaker will show how their ideas manifest themselves in nature and will discuss the implications of mathematical structure for some problems that occur in numerical simulations of processing flows.

9:15 am **James G. Glimm**
Courant Institute

Adaptive Computational Methods

Abstract: Difficulties in numerical approximation and finding the physically important domains in the solution of a problem usually coalesce in the same subregion of solution space. Typically, the space-time coordinates are the independent variables while the solution state space is described by dependent variables. Adaptive computations balance the computational effort, in either space, by working harder where the answer is more difficult and/or the answer is more important. The independent variables are represented by a grid and adaptivity for them refers to adaptive grid construction. This can be accomplished by a choice of nonuniform grid spacings or by use of refined grids inserted into or overlapping with a primary uniform grid. Multigrid methods should be viewed as adaptive also, with the localization of computational effort occurring in wave number space or momentum variables conjugate under Fourier Transform to space variables. State space variables also allow localized consideration, as in the case with nonlinear waves, eigenmodes, rate-limiting chemical reactions and the equilibrium treatment which eliminates (undesirable) transients in rapid solution modes. The speaker will demonstrate representative grid and state space adaptive methods, together with illustrations showing the use of these methods in practical examples.

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Paul Terwilliger University of Wisconsin	The Classification of P and Q Polynomial Association Schemes
Eiichi Bannai Ohio State University	Character Tables of Association Schemes
Dennis Stanton University of Minnesota	Orthogonal Polynomials of Classical Association Schemes
Richard Weiss Tufts University	S-Transitive and Distance Transitive Graphs

Working Group in Mathematical Aspects of Computer Graphics

4:45 pm **Vincent Hall 570** The Group meets weekly

This is an open discussion group on topics of interest to the participants. For example, software environments for geometry and graphics, implementation of rendering semi-algebraic sets, synthetic holography, using physical (or non-physical !) laws to automate animation ... We hope to produce pictures.

Monday, July 18

Today's talk will be in **Vincent Hall 16**

10:00 am **Coffee Break**

10:30 am	**Joseph A. Ball** Virginia Tech	Sensitivity Minization and Bitangential Nevanlinna-Pick Interpolation in Contour Integral Form

Abstract: The bitangential Nevanlinna-Pick interpolation problem is as follows: given row vectors

$$x_1, \cdots, x_m, y_1, \cdots, y_m,$$

column vectors

$$u_1, \cdots, u_n, v_1, \cdots, v_n$$

and points

$$z_1, \cdots, z_m, w_1, \cdots, w_n$$

in the right half plane π^+, find a rational matrix function $R(z)$ analytic and bounded in norm by 1 on π^+ for which

$$(1)\ x_i R(z_i) = y_i, \quad 1 \le r \le m$$

and

$$(2)\ R(w_j)u_j = v_j, \quad 1 \le j \le n.$$

If some w_i is equal to z_j then it turns out that a third condition

$$(3)\ x_i R(z_i) u_j = \rho_i \text{ if } z_i = w_j$$

(where the ρ_i's are preassigned numbers) is usually required. In this form, the extension to interpolation conditions of higher multiplicity becomes cumbersome and usually is not done in detail, although such problems are exactly what appear in some applications. A more compact way of writing the interpolation conditions is suggested by some work of A.A. Nudelman. Define matrices

$$C^+ = [v_1, \cdots, v_n], \quad C_- = [u_1, \cdots, u_n], \quad A_\pi = \text{diag}(w_1, \cdots, w_n), \quad A_\zeta = \text{diag}(z_1, \cdots, z_m)$$

$$B_+^T = [x_1^T, \cdots, x_m^T]^T, \quad B_-^T = [y_1^T, \cdots, y_n^T]^T$$

and

$$S = [S_{ij}], \quad (1 \le i \le m, \quad 1 \le j \le n)$$

where $S_{ij} = (y_1 u_j - x_i v_j)(z_i - w_j)^{-1}$ if $z_i \neq w_j$, and $S_{ij} = \rho_i$ if $z_i = w_j$.
Then the interpolation conditions (1), (2), (3) can equivalently be expressed in the contour integral form

$$(4)\ \ \frac{1}{2\pi j} \int_\gamma (zI - A_\zeta)^{-1} B_+ R(z) dz = B_-$$

$$(5)\ \ \frac{1}{2\pi j} \int_\gamma R(z) C_- (zI - A_\pi)^{-1} dz = C_+$$

and

$$(6)\ \ \frac{1}{2\pi j} \int_\gamma (zI - A_\zeta)^{-1} B_+ R(z) C_- (zI - A_\pi)^{-1} dz = S$$

where γ is a contour in the right half encircling all the points $z_1, \cdots, z_m, w_1, \cdots, w_n$. With this form, extensions to higher multiplicity are handled in a streamlined way; higher multiplicity bitangential interpolation corresponds simply to A_π and A_ζ having a more general Jordan form. A realization formula for the linear fractional parametrization of the set of all suboptimal solutions can be given explicitly in terms of the matrices C_+, C_-, A_π, A_ζ, B_+, B_-, S. This format is particularly well suited to obtaining state space solutions of the weighted sensitivity minimization problem in H^∞-control theory; via this approach, calculation of doubly coprime and inner-outer factorizations (as occur in the usual solutions) can be avoided.

4:00 pm **IMA Tea (and more!)** Vincent Hall 502 (The IMA Lounge)

Tuesday, July 19

3M IMA JOINT SYMPOSIUM IN SIGNAL PROCESSING

3M and IMA are holding a joint symposium in Signal Processing today in building 201 at the 3M complex in St. Paul beginning at 9:00 a.m.

IMA chartered buses will leave at 8:30 a.m. from the front of the Pillsbury Building, 310 Pillsbury Drive S.E. The meeting is open but attendees should have registered at the IMA office by July 11, 1988.

AGENDA

9:00 am	**Paul A. Pankow** Resource Vice President, Digital Imaging Applications Center/3M	Welcome
9:15 am	**Dr. Avner Friedman** Director, IMA	IMA mission and industry interaction
9:30 am	**Bill Weaver** Software & Electronics Resource Center/3M	Doppler Velocimetry Signal Processing
10:00 am	**Dr. A.B. (Bob) Mahmoodi** Digital Imaging Applications Center/3M	Image Processing
10:30 am	**Break**	

10:45 am	**Dr. Sailesh Rao** IMA (from AT&T)	Custom VLSI Architectures for Signal Processing

Abstract: Advances in CMOS VLSI technology have made it possible to achieve device densities on the order of 200,000 to a million devices on a single chip. The complexity of designing custom chips with such device densities is enormous even with state-of-the-art CAD tools, unless we use some structured design methodologies. The field of signal processing is uniquely situated in this respect, since many useful signal processing algorithms can be written in an iterative fashion. In this talk, we will discuss some techniques for mapping iterative algorithms on to processor array architectures, and show how these techniques were used in the custom design of a 10-multiplier adaptive filter chip. This adaptive filter chip can be used to do real-time 120-tap complex signal equalization at symbol rates upto 357kHz.

11:45 am	**Box Lunches**	Available in Auditorium
12:30 pm	**Guided Tours**	For Math Institute Guests
2:00 pm	**Dr. Fred Waltz** Engineering System & Technology Laboratory/3M	Real Time, Machine Vision System
2:30 pm	**Dr. Sig Soli** Bio Sciences Hearing Research Laboratory/3M	Fast and Efficient Signal Processing Techniques for Digital Hearing Aids
3:00 pm	**Break**	
3:30 pm	**Bernard Levy** University of California, Davis	Signal Processing Methods for Multidimensional Inverse Problems of Acoustic and Elastic Waves

Abstract: Over the past few years, a number of interesting new approaches have been proposed for multidimensional inverse problems of acoustic and elastic waves. These methods rely heavily on signal processing, optimization and systems concepts, and a brief overview of these advances will be presented. Inverse problems of acoustic and elastic waves are intrinsically *nonlinear*, and one approach to obtain practical inversion schemes consists in using approximations, such as the Born or Rytov approximation, which have the effect of linearizing the inverse problem about some known profiles, which represent our a priori knowledge of the medium. The resulting linearized inversion problem can then be formulated as a *generalized tomographic problem*, where the objective is to reconstruct a function, or set of functions, from weighted projections along isochron curves. Unlike in X-ray tomography, these curves are usually not straight lines, and for a variable background medium, they can in fact be quite arbitrary. Nevertheless, it turns out that an inverse generalized Radon transform (GRT) can be developed for these problems, which like for the straight line projection case, relies on back-projection and filtering operations. Another class of linearized inversion methods relies on the concept of *backpropagated wavefield*. In this approach, the observed scattered waves are propagated backwards in time into the scattering medium, and then imaged to yield a migrated image, which can then be filtered to obtain the desired inverse.

In addition to the above methods, *nonlinear iterative inversion methods* will also be discussed. This formulation relies on a system identification viewpoint, where the nonlinear inverse problem is formulated as a nonlinear least-squares problem, of usually huge dimension, which can then be solved iteratively by minimization techniques such as the conjugate gradient, or Newton algorithms. It will be shown that successive iteration steps of these algorithms can be interpreted in terms of the wavefield backpropagation and imaging approach developed for the linearized inversion case. In spite of its high computational burden, and of the fact that it is only guaranteed to converge to a local minimum, this formulation seems quite promising, and

future research directions arising in this context will be examined.

GUIDED TOURS
AT 3M-IMA JOINT SYMPOSIUM

The tours start at 12:30 pm and will take about 45 minutes, exclusive of transportation time. It is necessary to sign up for the tours in advance. You will be assigned to a tour on a first signed up-first served basis.

____ 1) Laser Images (a medical imaging system that produces high resolution medical images from body scans.) The imager is located in the Digital Imaging Applications center. Tourguide: Dr. Donald Singley.

____ 2) Tour of Hearing Aid Research Laboratory. Digital hearing and modeling. Feedback conditioning. Tourguide: Dr. Sig Soli

____ 3) Computerized vision systems (in Engineering Systems and Technology Laboratory). Tourguide: Dr. Fred Waltz.

____ 4) An expert system: KLUE (Knowledge Legacy of the Unavailable Expert) in the Artificial Intelligence Laboratory.

The buses will leave 3M at 5:00 pm and return to the IMA.

Wednesday, July 20

Today's talk is in **Vincent Hall 16**

9:00 am **Roger Brockett**, Harvard University — Local Versions of Fourier Expansions

Abstract: To be Announced.

10:00 am **Coffee Break**

Thursday, July 21

9:00 am **H.J. Woerdeman**, Free U. (Amsterdam) — Minimal rank completions of triangular operators

Abstract: The following problem will be discussed. Let a triangular operator be given. One can think of a triangular matrix or a voltera integral operator. Consider all operators with the same given triangular part. If in this class there is one with finite rank (for the integral operator this is the case when it is lowest separable), three is one with minimal rank. A formula for this minimal rank in terms of the given data is presented, as well as a way to construct all (which is sometimes only one) minimal rank extensions. Special cases (Toeplitz, difference kernels) and corollaries will be treated. For example, a theorem by Asplund (1954) concerning band matrices and their inverses appears as a corollary.

10:00 am **Coffee Break**

3:00 pm **Matt Grayson** — Vector Field Models for Nilpotent Lie Algebras with applications to Control Theory

UCSD & Geometry Supercomputer Project

Abstract: To approximate a control system, $x'(t) = E_1(x)+u(t)E_2(x)$, it is useful to have explicitly integrable vector fields F_1 and F_2 which closely approximate the system. In particular, the brackets of F_1 and F_2 should agree with the brackets of E_1 and E_2 as much as possible. To this end, we show how to find explicitly integrable vector fields with prescribed brackets at the origin in the free case, and in some quotient algebras.

As applications, we get a simple derivation of the Baker-Cambell-Hausdorff formula, and a quick proof of the Poincare-Birkhoff-Witt theorem.

This is joint work with Prof. Robert Grossman, UICC.

Friday, July 22

Today's talk is in **Vincent Hall 16**

9:00 am **Nicholas Young**
University of Glasgow

Error Analysis for H^∞ Design Methods Based on Hankel Operators

Abstract: The theorem of Adamyan, Arov and Krein [AAK, 1968] on best analytic approximation underlies numerous recently proposed approaches to the design of filters subject to an L^∞ -norm optimality criterion. An example is the "H^∞ disc method" [Helton and Schwartz], in which design specifications are converted to the requirement that the desired causal filter $H(j\omega)$ lie within a frequency-dependent tolerance $R(j\omega)$ of some ideal response $K(j\omega)$. Spectral factorization of $R^2(j\omega)$ allows the reduction of this problem to a form to which the AAK theorem applies. To compute H using this theorem one requires a satisfactory numerical representation of the Hankel operator H_ϕ with known symbol $\phi \in L^\infty$. In the event that ϕ is a rational function with a known state realization there is an effective way of representing H_ϕ and performing the necessary computations by state space methods [Glover 1984]. If, however, ϕ is known in some other way, e.g. by sampled data values, then it is less clear how H_ϕ can be computed, and indeed it will frequently be impossible in principle to represent H_ϕ by a finite matrix without truncation error. We address the problem of estimating the error (in the L^∞-norm) incurred in using the AAK theorem with the true operator H_ϕ approximated by a finite-dimensional restriction. More specifically, suppose g is the best H^∞ approximation to ϕ in the L^∞-norm and suppose $\tilde{g}$ is the approximation computed from the AAK formula but with H_ϕ replaced by its restriction to a finite-dimensional shift invariant subspace K_θ of H^2 (such subspaces are parametrized by finite Blaschke products θ). We obtain an estimate for $||g - \tilde{g}||_\infty$ showing that this error tends to zero as θ approaches the denominator of ϕ, the the sense that the zeros of θ approach the poles of ϕ.

10:00 am **Coffee Break**

Working Group in
Mathematical Aspects of Computer Graphics

4:45 pm **Vincent Hall 570** The Group meets weekly

This is an open discussion group on topics of interest to the participants. For example, software environments for geometry and graphics, implementation of rendering semi-algebraic sets, synthetic holography, using physical (or non-physical !) laws to automate animation ... We hope to produce pictures.

Week 5, July 25-31
Period of concentration: **Robust & nonlinear control with aerospace applications**

Monday, July 25

All talks are in **Vincent Hall 16**

Vincent Hall 16 is in the basement. Most of the offices of the participants and the mailboxes are located in the IMA facilities on the 5th floor of Vincent Hall.

Based on the interests of the participants, additional talks will be arranged today and scheduled for the remainder of the week. Contact the IMA Administrative Office for the updated schedule.

9:00 am **J.B. Pearson**, Rice University — Min-max Design of Digital Controllers

Abstract: New developments in linear control theory in recent years have led to the recognition that certain important practical problems have rather simple solutions that can be obtained using well developed and reliable computer software. In particular, H^∞ theory seeks to minimize the maximum error signal energy in a system subjected to bounded energy inputs and the most recent results in this area lead to iterative computations in which the steps involve solving eigenvalue problems and Riccati equations. Another approach is l-1 optimization in which the object of control is a discrete-time system and the objective is to minimize the maximum magnitude of the error sequence when the input sequences are bounded. In this case it is possible to construct rational controllers by solving linear programming problems and a set of linear equations. The l-1 approach is more recent and less well developed than the H^∞ approach and the objectives of this paper are to discuss current work in this area, isolate some of the problems, and demonstrate the application of the theory to robust and nonlinear control.

10:00 am **Coffee Break**

10:30 am **Gunter Stein**, Honeywell & MIT — Engineering Motivations for H_2/H_∞ Problems in Control

1:45 pm **M.A. Kaashoek**, Vrije University (Amsterdam) — Positive and Conjunctive Extension Problems

2:30 pm **E. Sontag**, Rutgers University — Co prime Factorization to Nonlinear Systems

3:00 pm **Coffee/Tea Break** — Vincent Hall 502

Tuesday, July 26

All talks are in **Vincent Hall 16**

9:00 am **Arthur Krener**, University of California, Davis — Nonlinear Controller Design via Approximate Normal Forms and the Q-Parametrization

Abstract: Most nonlinear design algorithms explicitly or implicitly depend on linear approximation and linear design techniques. We review recent advances in the theory of approximate normal forms of nonlinear systems and relate these to modern linear design methods, including the Q parametrization.

10:00 am **Coffee Break**

10:30 am **John Doyle**, Caltech — State-space solutions to standard $\mathcal{H}_2$ and $\mathcal{H}_\infty$ control problems

Abstract: For a standard $\mathcal{H}_\infty$ optimal control problem, simple state-space formulas are presented for all controllers parametrized as a linear-fractional transformation on a free parameter. Their computation involves just two Riccati equations, and the dimension of the controller equals that of the plant plus that of the free parameter. The central controller, obtained by setting the free parameter to zero, has a separation structure

reminiscent of classical LQG (i.e., $\mathcal{H}_2$) theory. The more standard $\mathcal{H}_2$-solution is developed in parallel, as its familiarity will facilitate the exposition of the new results.

1:45 pm	**J. Ball** Virginia Tech	Nonlinear Inner-outer Factorization
3:00 pm	**Dale Enns** Honeywell	Nonlinear Control Problems
4:00 pm	**IMA Tea (and more!)**	Vincent Hall 502 (The IMA Lounge)

Wednesday, July 27

All talks are in **Vincent Hall 16**

9:00 am	**Manfred Morari** Caltech	Control Structure Selection

Abstract: Much progress has been made recently on the development of design procedures for multivariable controllers which address robust performance – i.e., performance in the presence of model uncertainty. While these controllers provide interesting bounds on the achievable performance under exactly specified conditions, they can rarely be implemented in practice for a variety of reasons: high order, centralized structure, constraints/windup, etc. In practice, the control designer usually has a choice among different sets of actuators and measurements (different "control structures"). The selection of the control structure can have a profound effect on the achievable performance.
In this talk, the control structure selection problem will be motivated through a series of examples. Then a possible mathematical definition will be introduced and some bounds on the achievable performance (defined in the H_∞ context) will be derived for controllers with a specified (decentralized) structure. Limitations inherent in these techniques will be emphasized and new research directions will be suggested.

10:00 am	**Coffee Break**	
10:30 am	**E. Sontag** Rutgers University	The Equilinearization Approach to Nonlinear Control Design

Abstract: Recent papers by Rugh and Baumann, and by Reboulet, Champetier, and others, study families of linearizations of nonlinear systems around different operating points, and in particular the problem of obtaining compensators with the property that all closed-loop linearizations have the same dynamic behavior. In a similar spirit, we study linearizations along more arbitrary trajectories of nonlinear systems. This work is closely tied to the standard approach in engineering practice, where an open-loop trajectory is preplanned (using for instance nonlinear optimal control techniques,) and a servo is built using linear control theory in order to regulate along this reference motion. The regulated system then corrects for (small) disturbances and measurement errors. Essentially, we show how to build offline a nonlinear controller which, when presented with the particular motion to be followed, in effect behaves as a regulator along that motion. The design consists of two parts. In the first, one shows that any nonlinear controllable plant, under mild technical conditions, admits a precompensator with the following property: along control trajectories joining pairs of states, the composite system (precompensator plus plant) is, up to first order, isomorphic to a parallel connection of integrators. Systems along all possible such trajectories admit then the same linearization, hence the term "equilinearization". The second part consists of closing the loop using the alternative cooordinates in which the system is an integrator, and expressing the resulting system in terms of the original plant states. We shall provide a theorem showing that the closed-loop design indeed provides asymptotic stability along all reference motions and we give experimental results in order to illustrate the method with a simple example on momentum control of a rotating satellite.

1:45 pm	**Fred Bailey** University of Minnesota	Control Problems in Mechanical Motion Control

3:45 pm	**Art Krener** University of California, Davis	Nonlinear Controller Design via Approximate Normal Forms and the Q-Parametrization

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Thursday, July 28

All talks are in **Vincent Hall 16**

9:00 am	**M. Hazewinkel** Centrum voor Wiskundeen	Approximations Based on Lie Algebras for Filtering and Identification

Abstract: The socalled reference probability approach to nonlinear filtering problems - also called the unnormalized density approach, or the Lie algebraic approach - associates a Lie algebra of differential operators to a nonlinear filtering problem. This is the Lie algebra generated by the DMZ equation for an unnormalized version of the conditional density of the state. Using this Lie algebra with designated generators I shall discuss various approximation schemes and approximate filters. These approximations are global in nature and do not (as does the extended Kalman filter) rely on some sort of linearization around a working point or working trajectory. The same basic ideas have applications to the propagation of nongaussian initials by linear systems and to the identification of linear systems (which is a nonlinear problem).

10:00 am **Coffee Break**

10:30 am	**E.B. Lee** University of Minnesota	Linear Hereditary and Multidimensional Systems Theory

Abstract: The presentation will overview recent progress in development of analysis and synthesis techniques for systems involving transportation or computational delays. Such hereditary type systems have been extensively studied and there are results from the analysis and synthesis point of view related to finite dimensional systems theory and to certain infinite dimensional systems theory. The relationship to linear multidimensional systems will be discussed, including recent progress in finding computationally efficient and numerically stable algorithms for stability testing. Further, optimal control and feedback, stabilization for the hereditary and multidimensional systems will be covered. Finally, the task of providing approximate models of hereditary systems and multidimensional systems for various controller synthesis tasks will be described.

1:45 pm	**George Sell** IMA & University of Minnesota	An Introduction to Inertial Manifolds
3:00 pm	**Gilead Tadmor** Brown University	H^∞ Control Using the Pontryagin Maximum Principle

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Friday, July 29

All talks are in **Vincent Hall 16**

9:00 am	**Hector Sussmann** Rutgers University	Recent Results on Finite Dimensional Nonlinear Optimal Control

Abstract: The talk will describe recent developments in the study of the structure of optimal controls for nonlinear systems, with special emphasis on the analogies and differences with the linear case.

10:00 am **Coffee Break**

10:30 am	**Blaise Morton** Honeywell	To Be Announced

Working Group in

Mathematical Aspects of Computer Graphics

4:45 pm **Vincent Hall 570** The Group meets weekly

This is an open discussion group on topics of interest to the participants. For example, software environments for geometry and graphics, implementation of rendering semi-algebraic sets, synthetic holography, using physical (or non-physical !) laws to automate animation ... We hope to produce pictures.

CURRENT IMA PARTICIPANTS

LONG-TERM VISITORS IN RESIDENCE
One Month or Longer

Amini, A.	University of Minnesota	Jun 27 - Aug 5
Arimilli, Padu	3M	Jun 27 - Aug 1
Averbuch, Amir	Tel Aviv University	Jun 26 - Aug 5
Bellout, Hamid	Northern Illinois University	Jul 5 - Aug 5
Boley, Dan	University of Minnesota	Jun 27 - Aug 5
Bottema, Murk	Winona State University	Jun 26 - Jul 14 Jul 31 - Aug 5
Brannan, James	Clemson University	Jun 26 - Jul 15 Jul 31 - Aug 5
Butler, Lynne	Princeton U.	Jun 26 - Aug 31
Doerschuk, Peter	MIT	Jun 26 - Jul 23
Doyle, John	Caltech/Honeywell, Inc.	Jun 30 - Aug 5
Fabes, Eugene	University of Minnesota	Jun 27 - Aug 5
Faessler, Albert	Ecole d'Ingenieurs Biene	Feb 1 - Jul 30
Friedman, Avner	IMA	
Gaal, Lisl	University of Minnesota	Jun 27 - Aug 5
Gader, Paul	University of Wisconsin	Jun 27 - Jul 24
Games, Richard	MITRE Corp	Jun 27 - Aug 5
Garvan, Francis	U. of Wisconsin	Jun 26 - Jul 31
Habsieger, Laurent	U. Louis-Pasteur	Jun 26 - Jul 31
Hasenfeld, A.	Princeton U.	Jun 26 - Aug 6
Isakov, Victor	Courant Institute	Jun 17 - Jul 16
Itzikowitz, Samuel	Tel Aviv University	Jun 26 - Jul 23
Jerison, Meyer	Purdue University	Jun 26 - Jul 23
Kadell, Kevin	Arizona State University	Jun 27 - Aug 15
Kaveh, Mostafa	University of Minnesota	Jun 27 - Aug 5
Khargonekar, Pramod	University of Minnesota	Jun 27 - Aug 5
Kim, Myohngjin	University of Minnesota	Jun 27 - Aug 5
Kumar, Pat	University of Minnesota	Jun 27 - Aug 5
Lamken, Esther	IMA	Jun 26 - Sep 15
Lee, E. Bruce	University of Minnesota	Jun 27 - Aug 5
Lemke, Paul	IMA	Jun 27 - Aug 30
Li, Yanlin	University of Minnesota	Jun 27 - Aug 5
Lin, Shao-Shiung	National Taiwan University	Jun 15 - Aug 30
Luczak, Tomasz	Adam Mickiewicz U.	Jun 26 - Jul 31
Magagnosc, David	Dartmouth Coll.	Jun 26 - Aug 15
Miller, Willard	IMA	
Morton, Blaise	Honeywell Inc.	Jun 26 - Aug 5

Mugler, Dale	Santa Clara University	Jun 26 - Aug 5
Naevdal, Geir	University of Trondheim	Jun 24 - Aug 7
Reed, Todd	University of Minnesota	Jun 15 - Aug 5
Rejto, Peter	University of Minnesota	Jun 27 - Aug 5
Rennolet, Charles	3M	Jun 27 - Aug 5
Rocha, Ana Paula	U. Do Porto, Portugal	Jun 26 - Aug 5
Rocha, Maria Paula Macedo	U. of Groningen, Netherlands	Jun 26 - Aug 5
Sadjadi, Firooz	Honeywell Inc.	Jun 28 - Aug 5
Sell, George	University of Minnesota	
Sengupta, Sailes	South Dakota School of Mines	Jun 27 - Aug 5
Shelton, Chris	Honeywell Inc.	Jun 27 - Aug 5
Simion, Rodica	George Washington University	Jan 13 - Jul 31
Trick, Michael	Georgia Inst. of Tech.	Jun 26 - Aug 15
Walter, Gilbert	U. of Wisconsin, Milwaukee	Jul 10 - Aug 5
Werman, Michael	Brown University	Jun 26 - Jul 31
Wu, Zhe	University of Minnesota	Jun 27 - Aug 5
Yin, George	Wayne State U.	Jun 26 - Aug 6
You, Yuncheng	University of Minnesota	Jun 27 - Aug 5

SHORT TERM AND WORKSHOP VISITORS IN RESIDENCE

Auslander, Louis	CUNY	Jun 26 - Jul 1
		Jul 31 - Aug 5
Bailey, Fredric	University of Minnesota	Jul 25 - Jul 29
Ball, Joseph	Virginia Polytechnic Inst.	Jul 17 - Jul 30
Bistriz, Yuval	Tel Aviv University	Jul 8 - Jul 23
Blahut, Richard	University of Illinois, Urbana	Jul 31 - Aug 5
Boyd, Stephen	Stanford U.	Jul 11 - Jul 29
Bricogne, Gerard	U. Paris-Sud	Jul 6 -
Brockett, Roger	Harvard U.	Jul 17 - Jul 22
Bruckstein, Alfred	Technion (Israel)	Jul 11 - Jul 22
Byrnes, Chris	Arizona State U.	Jul 25 - Jul 29
Davies, D. Huw	University of Edinburgh	Jun 26 - Jul 10
		Jul 31 - Aug 5
Desai, Mita	Honeywell	Jun 28 - Jul 15
Dwyer, Tom	U. of Illinois-Urbana	Jul 25 - Jul 29
Enns, Dale	Honeywell	Jul 26 - Jul 26
Francis, Bruce	U. of Toronto (Ontario)	Jul 3 - Jul 8
		Jul 25 - Jul 29
Fuhrmann, Paul	Ben-Gurion U. of Negev	Jul 9 - Jul 24
Georgiou, Tryphon	Iowa State U.	Jul 11 - Jul 23
Gertner, Izidor	Technion - Israel	Jul 3 - Jul 15
		Jul 31 - Aug 5
Gohberg, I.C.	Tel Aviv U.	Jun 27 - Jul 2
		Jul 12 - Jul 19
		Aug 1 - Aug 5
Grunbaum, Alberto	U. of California-Berkeley	Jun 26 - Jul 1
		Jul 31 - Aug 6
Hazewinkel, M.	Stichting Math. Centrum	Jul 25 - Jul 29
Helton, William	U. of Calif.-San Diego	Jun 27 - Jul 2
		Jul 17 - Jul 30
Hunt, Robert	U. of Texas-Dallas	Jul 24 - Jul 29
Izen, Steven	Case Western Reserve	Jul 30 - Aug 5
Johnson, Charles	College William & Mary	Jul 10 - Jul 29

Kaashoek, M.A.	Vrije U. (Amsterdam)	Jul 12 - Jul 27
Kailath, Tom	Stanford U.	Jun 26 - Jun 29
		Jul 10 - Jul 15
		Jul 18 - Jul 23
Krener, Arthur	U. of Calif.-Davis	Jul 24 - Jul 29
Lev-Ari, Hanoch	Stanford U.	Jul 11 - Jul 15
Levy, Bernard	U. of Calif.-Davis	Jul 11 - Aug 5
Makhoul, John	BBN Laboratories Inc.	Jul 31 - Aug 5
McClure, Donald	Brown University	Jul 31 - Aug 5
McDonald, Bernard	NSF	Jul 21 - Jul 21
Mitter, Sanjoy	MIT	Jun 26 - Jul 2
		Jul 17 - Jul 23
Parzen, Emanuel	Texas A&M University	Jul 4 - Jul 15
Pearson, Boyd	Rice U.	Jul 25 - Jul 29
Quinto, Eric Todd	Tufts U.	Jul 31 - Aug 6
Ran, Andre C.M.	Vrije U.(Amsterdam)	Jul 9 - Jul 30
Rao, Sailesh	AT&T Bell Labs.	Jul 11 - Jul 22
Siejko, Kris	Honeywell Inc.	Jun 27 - Jul 15
Sontag, Eduardo	Rutgers U.	Jul 23 - Jul 30
Sussman, Hector	Rutgers U.	Jul 27 - Jul 31
Tadmor, Gilead	Brown University	July 27 - Jul 29
Tsao, Anna	AT& T Bell Labs	Jun 26 - Jul 10
		Jul 31 - Aug 5
Walker, Elbert	NSF	Jul 21 - Jul 21
Whitehouse, Harper	Naval Ocean System Sci.	Jul 31 - Aug 5
Willems, Jan	U. of Groningen	Jul 3 - Jul 22
Winograd, Shmuel	IBM	Jul 6 - Jul 9
Witten, Matthew	ETA Systems	Jul 10 - Jul 31
Woerdeman, Hugo	Free U. (Amsterdam)	Jul 11 - Jul 22
Yagle, Andrew	U. of Michigan	Jul 24 - Aug 5
Young, Nicholas	Glasgow U. (Scotland)	Jul 11 - Jul 29
Zayed, Ahmed	Calif. Polytec. State U.	Jul 10 - Jul 15

INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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IMA NEWSLETTER #121

August 1 - August 31, 1988

1988 Summer Program
SIGNAL PROCESSING

NEWS AND NOTES

Summer Program on SIGNAL PROCESSING

June 27-August 5, 1988

Organizers: T. Kailath (Chairman), L. Auslander
A. Grunbaum, W. Helton, P. Khargonekar, S. Mitter

The program is an integrated approach to one-dimensional and multidimensional problems in Signal Processing. The first two weeks were devoted to a broad range of problems and methods. Efforts were made to promote new interaction also within one-dimensional research groups (such as the linear control and the nonlinear control people) and within the multi-dimensional groups (such as radar, sonar and medical imaging). The next four weeks are somewhat less structured and have included periods of concentration in both 1-dimensional and multidimensional topics.

Tutorial Seminar on Solitons

During the week September 6-9, 1988, immediately preceding the first workshop of the Nonlinear Waves program, a tutorial seminar introducing graduate students and post-docs to the basics of solitons will be run by David Sattinger and Peter Olver. The seminar will be conducted informally, with participation by post-docs already conversant in solitons and visitors who are in residence at the time. Texts that will be used include Alan Newell's book "Solitons in Mathematics and Physics" and Ablowitz and Segur's "Solitons and the Inverse Scattering Transform". Topics that will be touched on include derivation of the Korteweg-deVries and other soliton equations, properties of solitons, inverse scattering, Hamiltonian methods, conservation laws and perturbation methods. The material will be presented with no assumed prerequisites and as preparation for the Workshop on Mathematical Theory of Solitons the following week.

PARTICIPATING INSTITUTIONS:Indiana University, Iowa State University, Michigan State University, Northern Illinois University, Northwestern University, Ohio State University, Purdue University, University of Chicago, University of Cincinnati, University of Illinois (Chicago), University of Illinois (Urbana), University of Iowa, University of Michigan, University of Minnesota, University of Notre Dame, Wayne State University
PARTICIPATING CORPORATIONS:Bellcore, Cray Research, Eastman Kodak, Honeywell, 3M

SCHEDULE FOR AUGUST 1 - 31

Summer Program on
SIGNAL PROCESSING
June 27-August 5, 1988
Organizers: T. Kailath (Chairman), L. Auslander
A. Grunbaum, W. Helton, P. Khargonekar, S. Mitter

Week 6, August 1-5
Problems in radar, sonar & medical imaging

Unless otherwise noted, all talks are in **Vincent Hall 16**

Vincent Hall 16 is in the basement. Most of the offices of the participants and the mailboxes are located in the IMA facilities on the 5th floor of Vincent Hall.

Monday, August 1

9:00 am **Andrew Yagle**
University of Michigan

Generalized Split Levinson, Schur, and Lattice Algorithms for Three-Dimensional Random Field Estimation Problems

Abstract: Fast algorithms for computing the linear least-squares estimate of a three-dimensional random field from noisy observations inside a sphere are proposed. The algorithms can be viewed as generalized split Levinson, Schur, and lattice algorithms, since they exploit the (assumed) Toeplitz structure of the double Radon transform of the field co-variance, and therefore they require fewer computations than would solution of the multidimensional Wiener-Hopf integral equation. Unlike previous generalized Levinson algorithms, no quarter-plane or asymmetric half-plane support assumptions for the filter are necessary; nor is the multidimensional filtering problem treated as a multichannel (vector) filtering problem.

The algorithms work in three stages. First, the generalized split Schur algorithm computes a potential from the covariance of the random field. This potential is a three-dimensional generalization of the parameter appearing in the split Levinson algorithm. Alternatively, the generalized split lattice algorithm may be used to compute the potential from the canonical spectral factor of the covariance of the observation field. Next, the generalized Levinson algorithm computes the Radon transform of the generalized prediction filter for estimating the random field on the surface of the sphere of noisy observations. Finally, this filter is used to compute the smoothing filter for estimating the random field inside the sphere of observations. The algorithms generalize known results for isotropic, two-dimensional random fields.

10:00 am **Coffee Break**

10:30 am **Alfred Louis**
Technische Universitat Berlin

The Eikonal Approximation in Ultrasound CT

Abstract: The mathematical model in ultrasound computerized tomography is the stationary Schrodinger equation where the potential is to be determined. Frequently applied methods are the short wavelength approximations of Born and Rytov. In 1947 Moliere suggested the eikonal approximation which in mathematical terms can be thought of as an approximation of the parametrix by an averaging of the potential over lines. This method for treating the forward problem was investigated by Glauber in 1959 and he showed that the method has, from a physical point of view, better properties than WKB and Born or Rytov approximations.

Starting from this mathematical model we investigate the inverse problem and we are led to the x-ray transform of the potential. We study the stability and the resolution for a finite number of data, and we treat the numerical problem.

2:00 pm **Discussion** Vincent Hall 16

Professors Auslander and Grunbaum will conduct a discussion among the participants to decide on topics and speakers for the rest of the week.

3:00 pm **Kennan Smith** Local and Global Tomography
Oregon State University

Abstract: The formulas of ordinary tomography for the recovery of a density function f from multiple x-rays are global. Recovery of the value at a single point requires x-rays of a full cross section of the object. Recovery of Λf (Λ is the square root of the negative Laplacian) is local. Here $\Lambda f(x)$ can be recovered from attenuation measurements along rays arbitrarily close to x.
The formulas for local and global tomography will be discussed, primarily from the point of view of numerical implementation and the choices of the point spread function, placement of the x-ray detectors, number of x-ray sources, etc.

4:15 pm **IMA Tea (and more!)** Vincent Hall 502 (The IMA Lounge)

Tuesday, August 2

9:00 am **John Makhoul** Vector Quantization
BBN Laboratories Inc.

Abstract: Quantization, the process of approximating continuous-amplitude signals by digital (discrete-amplitude) signals, is an important aspect of data compression or coding, the field concerned with the reduction of the number of bits necessary to transmit or store analog data, subject to a distortion or fidelity criterion. The independent quantization of each signal value or parameter is termed scalar quantization, while the joint quantization of a block of parameters is termed block or vector quantization. This talk gives the basic concepts employed in vector quantization, presents a model with examples which show why and how vector quantization works, and gives an assessment of the benefits and costs of vector quantization when compared to scalar quantization.

10:00 am **Coffee Break**

10:30 am **Donald E. McClure** Bayesian Statistical Methods for Tomographic
Brown University Image Reconstruction

Abstract: The reconstruction problem for SPECT (single photon emission computed tomography is formulated as a statistical estimation problem: *estimate the nonhomogeneous intensity function of a two- (or three-) dimensional Poisson process from indirect observations*. Previously, this has been addressed using the principle of maximum likelihood, but the likelihood method does not incorporate spatial constraints. Alternatively, spatial information about the unknown intensity function can be described by a Gibbs prior distribution and this then leads to Bayesian methods for the reconstruction (estimation) problem. Bayesian reconstrutions are described and illustrated by examples using both real and simulated data. A parameter estimation problem for the Gibbs prior distributions is posed. Two methods are suggested and illustrated for the subsidiary parameter estimation problem. Computational algorithms are given.

11:00 am **Andrew Hasenfeld** Selective 'complex' reflectionless potentials
Princeton University

Abstract: A pictorial survey is presented of the application of nonlinear wave techniques to NMR (nuclear magnetic resonance). The language of inverse scattering provides a convenient framework in which to attempt to answer the question of why simple nonlinear spin physics is comprehensible. This work, done largely in collaboration with F.A. Grunbaum, includes not only the analytical tools provided by nonlinear mathematicians, but also numerical experimentation and, most importantly, physical measurements that confirm these ideas.

2:00 pm **Wavelet Seminar** Vincent Hall 570

Abstract: Gilbert Walter will give the first talk. A basic reference for the seminar is the preprint "The wavelet transform, time frequency localization and signal analysis" by Ingrid Daubechies. Copies of the preprint are available on the shelves outside the IMA Administrative Office (Vincent Hall 514).

Wednesday, August 3

9:00 am **R.E. Blahut** Who needs the ambiguity function?
University of Illinois, Urbana/IBM

Abstract: This tutorial talk will define and catalogue the properties of the ambiguity function and describe its role in radar, sonar, and emitter location systems.

9:30 am **Todd Quinto** Tomographic reconstructions from incomplete
Tufts University data: numerical inversion of the exterior Radon transform

Abstract: X-ray CT can be used for the non-destructive evaluation of rocket exit cones and bodies [Shepp and Srivastava] with centers that do not need to be reconstructed. The speaker's algorithm for tomography around the beating heart is being modified for reconstructions without using data through the center. Defects such as delaminations in rocket exit cones and separations in rocket body gaskets are easily seen from such data and perhaps small scanners could be made to acquire the data on site.
Reconstructions of mathematical phantoms including preliminary results for the industrial problem are given and a description of the completed algorithm is presented. A wave front set analysis is given that predicts weaknesses inherent in any reconstruction algorithm that uses incomplete data.

10:00 am **Coffee Break**

10:30 am **Louis Auslander** Ambiguity functions and the Dirac
CUNY Representation of the Heisenberg group

Abstract: We will define all the terms in the title and show some implications for the correspondence for the range of the ambiguity operator.

11:00 am **Gil Walter** Some recent extensions of the sampling theorem
U. of Wisconsin, Milwaukee

Abstract: The classical Shannon sampling theorem enables one to reconstruct a band limited analog signal in $L^2(R')$ from its values on the integers. Some recent extension have been made to (i) band limited functions of polynomial growth, (ii) transforms associated with orthogonal systems other than the trigonometric.

11:30 am **Kennan Smith** Sharpening of Mammograms
University of Oregon

Abstract: Dr. Smith will show a VCR tape with examples of sharpening of mammograms.

2:00 pm **Wavelet Seminar** Vincent Hall 570

Chris Heil of the University of Maryland and MITRE Corporation will speak.

4:00 pm	**Vincent Hall 570**	Seminar on Markov Random Fields

The Seminar will be lead by Donald McClure and Sanjoy Mitter.

Thursday, August 4

9:00 am	**E. Feig** IBM	Estimating interesting portions of ambiguity functions

Abstract: In radar we are usually interested in estimating the ambiguity surface around a small region about the origin. We discuss various methods for efficiently doing these estimations.

9:30 am	**Izador Gertner** Technion - Israel	On Narrow Band and Broad band Ambiguity Functions

Abstract: Computational properties and algorithms will be discussed.

10:00 am	**Coffee Break**	

10:30 am	**Tom Ramsey** MITRE Corp	Stability of Time-Varying Auto-Regressive (AR) Filters

Abstract: Auto-regressive filters are linear operators $L(u) = y$ on causal sequences defined by a recursion relation

$$y_n + \sum_{j=1}^{k} a_j^{(n)} y_{n-j} = u_n.$$

The poles at time n are the roots of $P^{(n)}(z) = z^k + \sum_{j=1}^{k} a_j^{(n)} z^{k-j}$. The filter is stable if $y = L(u)$ is bounded when u is bounded. Necessary and sufficient conditions are obtained for stability, together with computable criteria for periodic coefficients updated at regular intervals.

11:00 am	**Jim Brannan** Clemson University	Some Signal Processing Problems in Underwater Acoustics

Abstract: Environmental acoustics is concerned with the effects of the environment upon the propagation of acoustic waves through an ocean medium, or, in the language of communication theory, the effects of a complex communication channel, the ocean, or transmitted acoustical signals. On the other hand, statistical signal processing methods have traditionally been developed for very idealized communication channel models. I would like to discuss some problems which arise from the synthesis of ideas from these two disciplines, eg., implications for ambiguity-like functions, modeling problems, and computational difficulties.

2:00 pm	**Marvin Bernfeld** Raytheon Co.	Tomography in radar

Abstract: An example of radar imaging is mapping echo intensities with respect to range and Doppler shift. Recently, a novel approach has been conceived to produce such images as a result of the discovery that analogous imaging projections employed in medicine for x-ray tomography, are possible in radar systems incorporating linear frequency (CHIRP) modulation pulse compression.

2:30 pm	**D. Snyder & J. O'Sullivan** Washington University	The use of maximum-likelihood estimation for forming images of diffuse radar-targets from delay-doppler data

Abstract: (Joseph O'Sullivan will speak.) In this paper, we present a new approach to high-resolution radar imaging. The starting point is a model of the radar echo-signal based on the physics governing radar

reflections. This model has been used several times in the past for describing radar targets that are rough compared to the wavelength of the transmitted radiation. Without specifying precisely what the transmitted signal is, we derive a general-based procedure for obtaining images. After discretizing the model, the radar imaging problem reduces to the task of estimating discretized second-order statistics of the reflectance process of the target. A maximum-likelihood estimate of these statistics is obtained as the limit point of an expectation-maximumization algorithm. (Joint work with M.I. Miller.)

3:15 pm	**IMA Tea (and a bit more!)**	Vincent Hall 502 (The IMA Lounge)
3:45 pm	**H.J. Whitehouse** Naval Ocean Systems Center	Delay-doppler radar/sonar imaging

Abstract: New techniques for the processing of non stationary signals when combined with modern tomographic imaging methods may improve the mapping of delay-Doppler target distributions. If the relationship of the delay-Doppler distribution to the range and cross-range properties of a rotating rigid body is used, then a reconstruction of the image of a rigid body is possible. The two new signal processing concepts utilized here are the application of high resolution time-frequency analysis and two-dimensional tomographic reconstruction.

4:15 pm	**Harold Naparst** UC Berkeley	Radar Signal Choice and Processing for a Dense Target Environment

Abstract: Consider a dense group of reflecting radar objects moving with different velocities and at different ranges. The problem is to determine the density of targets at every range and velocity. The problem of how to choose the outgoing signals and how to process the echoes of those signals from the targets so as to determine the density function is discussed. The problem is a classical inverse problem. The object is to reconstruct a function of two variables (range and velocity) from limited information. Two schemes are given. The first of these methods modifies the method of Klauder and Wilcox to the case of signals with a large range of frequency components (wideband signals). The second is an improvement on the first which uses a formula of Khalil from affine group theory. It will be seen that this work is closely related to the "wavelet" work recently completed by Daubechies and Meyer. Numerical simulations support the conclusions.
This paper is a summary of the author's Ph.D. dissertation, which may be ordered from University Microfilms, Inc.

Friday, August 5

9:00 am	**Steven Izen** Case Western Reserve University	Inversion of the X-ray Transform from Data in a Limited Angular Range

Abstract: The experimental technique of Diffuse Illumination Heterodyne Holographic Interferometry can provide data which correspond to line integrals (or the x-ray transform) of the index of refraction of a flowing gas, which in turn is proportional to the density. In the application of this technique to the recovery of density of a supersonic flow between compressor blades of jet engines the viewing range is severely restricted. The problem can be formulated mathematically as the inversion of the x-ray transform from data in a limited angular range. An orthogonal function expansion approach has lead to a theoretical inversion for the x-ray transform. Numerical experiments are now being performed to determine the Singular Value Decomposition for the restricted view transform and to obtain a fully three dimensional reconstruction.

9:30 am	**Donald C. Solmon** Oregon State University	Filtered Back Projection and the Exponential Radon and X-ray Transforms

Abstract: We show that (essentially) the only generalized Radon transforms for which one can expect filtered back projection inversion and approximate inversion formulas are the exponential Radon transforms. We show that filters exist corresponding to an arbitrary point spread function for inverting the variably attenuated exponential Radon transform, and give explicit formulas for filters for inverting the constantly

attenuated exponential x-ray transform. The latter operator arises in single photon emission computed tomography. (This is joint work with I.A. Hazou)

10:00 am **Coffee Break**

10:30 am Round Table on New Mathematical Methods in Radar

August 8-31

There will be no formal program at the IMA during this period, as the staff prepares for the 1988-89 academic year program: NONLINEAR WAVES. However, there will be a number of visitors in residence and talks will be scheduled each week on an informal basis. Call or drop in at the IMA Adminisrative Office for the latest information.

Thursday, August 11

SPECIAL LECTURE

2:00 pm **Taro Yoshizawa**
Okayama Univ., Japan

Periodic and almost periodic solution on a Volterra equation with infinite delay

Abstract: We discuss the existence of a periodic and almost periodic solution on a Volterra equation with infinite delay, under the condition that the equation has a bounded solution on $[0, \infty)$ which has some stability property. To do this, we introduce some kinds of stability properties in a certain sense. Our results can be applied to the existence of a strictly positive periodic (almost periodic) solution of a model of dynamics of an n-species system in mathematical ecology.

The talk will be given in Vincent Hall 570

Monday, August 29

SPECIAL LECTURE

11:15 am **Jean-Claude Nedelec**
Ecole Polytechnique, Palaiseau

Mathematical Results for Radiation Patterns for Arrays of Antennas

The talk will be given in Vincent Hall 570

CURRENT IMA PARTICIPANTS

LONG-TERM VISITORS IN RESIDENCE
One Month or Longer

Bellout, Hamid	Northern Illinois University	Jul 5 - Aug 6
Bottema, Murk	Winona State University	Jun 26 - Jul 14
		Jul 31 - Aug 5
Brannan, James	Clemson University	Jun 26 - Jul 15
		Jul 31 - Aug 5
Butler, Lynne	Princeton U.	Jun 26 - Aug 31
Dix, Daniel	University of Chicago	Aug 28 - Sep 1, 1989

Doyle, John	Caltech/Honeywell, Inc.	Jun 30 - Aug 5
Fabes, Eugene	University of Minnesota	
Friedman, Avner	IMA	
Gaal, Lisl	University of Minnesota	Jun 27 - Aug 5
Hasenfeld, A.	Princeton U.	Jun 26 - Aug 6
Johnson, Robert	Ctr. for Large Scale Comput.	Jun 27 - Jul 28
		Aug 1 - Aug 5
Kadell, Kevin	Arizona State University	Jun 27 - Aug 15
Kaup, David	Clarkson University	Aug 16 - Dec 15
Kaveh, Mostafa	University of Minnesota	Jun 27 - Aug 5
Khargonekar, Pramod	University of Minnesota	Jun 27 - Aug 5
Kim, Myohngjin	University of Minnesota	Jun 27 - Aug 5
Kumar, Pat	University of Minnesota	Jun 27 - Aug 5
Lamken, Esther	IMA	Jun 26 - Sep 1
Lee, E. Bruce	University of Minnesota	Jun 27 - Aug 5
Lemke, Paul	IMA	Jun 27 - Aug 30
Li, Yanlin	University of Minnesota	Jun 27 - Aug 5
Lin, Shao-Shiung	National Taiwan University	Jun 15 - Sept 15, 1989
Magagnosc, David	Dartmouth Coll.	Jun 26 - Aug 25
Miller, Willard	IMA	
Mugler, Dale	Santa Clara University	Jun 26 - Aug 5
Naevdal, Geir	University of Trondheim	Jun 24 - Aug 7
Olver, Peter	University of Minnesota	
Pedrigal, Paublo	University of Minnesota	Jul 15 - Aug 31
Ramachandran, K.M.	University of South Florida	Jun 26 - Aug 5
Reed, Todd	University of Minnesota	Jun 27 - Aug 5
Rejto, Peter	University of Minnesota	Jun 27 - Aug 5
Rennolet, Charles	3M	Jun 27 - Aug 5
Rocha, Ana Paula	U. Do Porto, Portugal	Jun 26 - Aug 3
Rocha, Maria Paula Macedo	U. of Groningen, Netherlands	Jun 26 - Aug 5
Sadjadi, Firooz	Honeywell Inc.	Jun 28 - Aug 5
Sell, George	University of Minnesota	
Sengupta, Sailes	South Dakota School of Mines	Jun 27 - Aug 5
Shelton, Chris	Honeywell Inc.	Jun 27 - Aug 5
Szmigielski, Jacek	University of Virginia	Aug 28 - Dec 31
Trick, Michael	Georgia Inst. of Tech.	Jun 26 - Aug 15
Walter, Gilbert	U. of Wisconsin, Milwaukee	Jul 10 - Aug 5
Werman, Michael	Brown University	Jun 26 - Aug 31
Weinberger, Hans	University of Minnesota	
Witten, Matthew	ETA Systems	Jul 10 - Aug 5
Wu, Zhe	University of Minnesota	Jun 27 - Aug 5
Yin, George	Wayne State U.	Jun 26 - Aug 6
You, Yuncheng	University of Minnesota	Jun 27 - Aug 5
Zhao, Van-chun	Fudan University	Aug 29 - Jun 30, 1989
Zurkowski, Victor	Yale University	Aug 15 - Aug 31, 1989

SHORT TERM AND WORKSHOP VISITORS IN RESIDENCE

Auslander, Louis	CUNY	Jun 26 - Jul 1
		Jul 31 - Aug 5
Benke, George	MITRE Corp	Aug 1 - Aug 5
Bernfeld, Marvin	Raytheon Co.	Aug 4 - Aug 5
Blahut, Richard	University of Illinois, Urbana	Jul 31 - Aug 5
Davies, D. Huw	University of Edinburgh	Jun 26 - Jul 10

		Jul 28 - Aug 7
Evans, Ward	MITRE Corp	Aug 1 - Aug 5
Feig, Ephraim	IBM	Aug 1 - Aug 5
Friedel, Mike	Bureau of Mines	July 21 - Aug 5
Gertner, Izidor	Technion - Israel	Jul 3 - Jul 15
		Jul 31 - Aug 5
Gohberg, I.C.	Tel Aviv U.	Jun 27 - Jul 2
		Jul 12 - Jul 19
Green, Leon	University of Minnesota	
Grunbaum, Alberto	U. of California-Berkeley	Jun 26 - Jul 1
		Jul 31 - Aug 6
Haerle, Mark	Honeywell Inc.	Aug 4 - Aug 4
Heil, Chris	MITRE Corp	Aug 3 - Aug 5
Hendricks, W. James	MITRE Corp	Aug 1 - Aug 5
Izen, Steven	Case Western Reserve	Jul 30 - Aug 5
Le Page, Raoul	Michigan State University	Aug 15 - Aug 16
Level, Eric	U. of Wisconsin, River Falls	July 21 - Aug 5
Levy, Bernard	U. of Calif.-Davis	Jul 11 - Aug 2
Louis, Alfred	Tech. U. of Berlin	Aug 1 - Aug 5
Makhoul, John	BBN Laboratories Inc.	Aug 1 - Aug 5
McClure, Donald	Brown University	Jul 31 - Aug 5
Mitter, Sanjoy	MIT	Jun 26 - Jul 2
		Aug 1 - Aug 4
Naparst, Harold	UC Berkeley	Aug 3 - Aug 5
O'Sullivan, Joseph	Washington University	Jul 31 - Aug 5
Polling, Craig	Honeywell	Aug 4 - Aug 4
Quinto, Eric Todd	Tufts U.	Jul 31 - Aug 6
Ramsey, Thomas	MITRE Corp	Aug 1 - Aug 5
Richardson, Tom	MIT	Jul 31 - Aug 5
Rosenbloom, Paul	Columbia University	Aug 20 - Sep 2
Smith, Kennan	Oregon State U.	Aug 1 - Aug 5
Snyder, Donald	Washington University	Jul 31 - Aug 5
Solmon, Donald	Oregon State U.	Aug 1 - Aug 5
Tsao, Anna	AT&T Bell Labs	Jun 26 - Jul 10
		Jul 31 - Aug 5
Vergara-Caffarelli, G.	U. of Trento, Italy	Aug 4 - Aug 26
Weigel, Charles	Honeywell	Aug 1 - Aug 5
Whitehouse, Harper	Naval Ocean System Sci.	Jul 31 - Aug 5
Yagle, Andrew	U. of Michigan	Jul 24 - Aug 5
Yoshizawa, Taro	Japan	Aug 10 - Aug 13